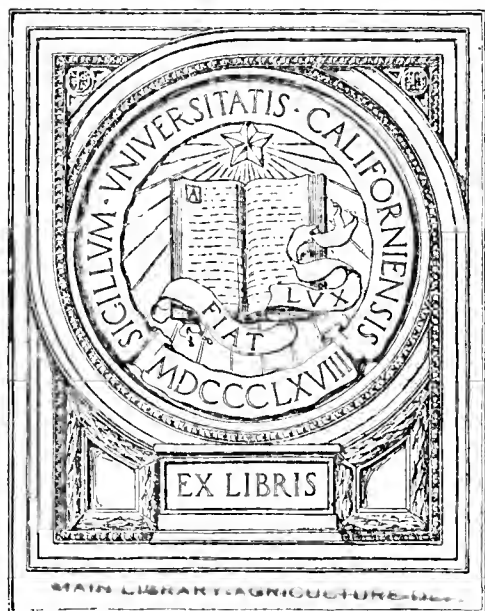


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Bulletin No. 20.

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# THE FIXATION OF ATMOSPHERIC NITROGEN

A Communication made to the Cairo  
Scientific Society, January 3, 1919, by

FRANK HUGHES.

(Edited by the Publication Committee of the Ministry of Agriculture.)

**Government Press, Cairo, 1922.**

To be obtained either directly or through any Bookseller, from  
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1870

1871

1872

1873



## PREFATORY NOTE.

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In view of the fact that the suggestion to use some of the water power available at Aswân for the production of fertilizers has again been revived the following may be of interest.

This communication was made to the Cairo Scientific Society on January 3, 1919, but owing to the temporary suspension of the Cairo Scientific Journal it was not published. The paper was illustrated by slides, mainly of the plant employed. These are not reproduced. An Appendix containing the results of some experiments with nitrogenous fertilizers on maize is added, as these results were referred to and the photographs exhibited.

F. H.



# MINISTRY OF AGRICULTURE, EGYPT.

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## Bulletin No. 20.

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### THE FIXATION OF ATMOSPHERIC NITROGEN.

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The question of the fixation of atmospheric nitrogen has a peculiar interest at the present time. During the past five years the importance of growing a very large proportion of one's food has been brought home in a very forcible manner to most nations. It has been seen in England during the war how little of its food supply was produced at home and how dependent Great Britain was on supply from outside and generally from a very considerable distance. Now in a densely populated country the area under food crops cannot be very largely augmented ; it is true that some land formerly unproductive or nearly so has been brought under the plough and is yielding a small supply of wheat or other cereal but this means the addition of some few per cent only to the total crop. Apart then from the bringing of fresh land under cultivation two other means exist of increasing the crops. The one is to produce more heavily yielding varieties of corn, the other is to increase the yield by the employment of much larger quantities of fertilizing materials. Of these two the latter seems to be more promising. It is true that of later years many new and heavy yielding varieties of the more important farm crops have been produced, but the difference in the yield of these and those formerly grown, though fairly considerable, is not sufficient to justify one in relying entirely on this method for a solution. We must make use of the best varieties of corn and then grow them under such cultural conditions as regards a supply of fertilizing materials as will ensure them producing a maximum yield.

As I have pointed out on a previous occasion, there are three elements which are of fundamental importance as fertilizing materials. These are : nitrogen, potash, and phosphorus. To be of value to the plant these must be combined in certain forms in which they are soluble in water or at any rate in very weak acid.

Each class of plant has its own dominant fertilizing ingredient, and in the case of the cereals this is nitrogen.

As a result we rarely find that a cereal crop is starving for want of potash, though it is true such a thing might happen on very poor land, but we invariably find that a wheat or other cereal crop is greatly benefited, the yield of grain and straw being both increased, by the application of a suitable nitrogenous fertilizer.

For some years the chief sources of nitrogenous fertilizers have been the nitrate fields of South America and the sulphate of ammonia now produced in such large quantities in several industries. It has for a long time been realized that the nitrate fields of Chile are by no means inexhaustible, and although the estimates as to the time they will suffice to supply the world's demands are—as such estimates must necessarily be—somewhat discrepant, still the fact remains that some time or other, and that not very distant, the cost of nitrate of soda will be much increased owing to the fact that only comparatively poor material will remain to be worked.

In addition to this important and extensive use of nitrates in agriculture it must also be remembered that nitrate of soda was, until quite recently, the only raw material used in the production of nitric acid. Nitric acid is one of the most important of the so-called heavy chemicals, as it is essential for the production of practically all the more common explosives as well as for the manufacture of synthetic drugs and dyes.

The atmosphere contains some 4,000 billion tons of nitrogen, or to put it in a manner which is more intelligible—vast figures really convey but little—the nitrogen in the air resting on one square metre of the earth's surface would be sufficient to produce some forty to fifty tons of nitrate of soda.

It is rather more than 130 years ago that the Hon. Henry Cavendish made his remarkable "Experiments on Air" in which he showed for the first time that the air consisted of oxygen and nitrogen in the proportion of one to four. This he did by passing electric sparks through a small quantity of air confined over mercury. After the sparks had been passing for some time the volume of air was seen to have diminished and on applying some lime water or other alkaline liquid the volume was still further reduced. By the passage of the sparks through the air oxides of nitrogen are produced. These are absorbed by the alkaline solution with the formation of nitrates and nitrites. More pure oxygen was then added and the sparking continued; excess of oxygen was removed by a suitable reagent, generally sulphide of potassium, and it was then found that only a very minute bubble of gas remained. This bubble, as was shown more than a hundred years later, was Argon. By this remarkable experiment, then, Cavendish had demonstrated the true composition of the atmosphere and, although he did not recognize the fact, had discovered argon and

shown the way in which the nitrogen of the air could be rendered useful.

With the invention of the dynamo, powerful electric currents soon became available, and it was not many years before numerous patents were taken out for the production of nitric acid and nitrates from the air by electrical means. All these, however, proved too costly and were never commercially successful, if indeed they ever passed the purely experimental stage.

In 1890 Sir W. Crookes exhibited a "flaming arc" produced by a current of very high voltage and showed that the flame was really due to the combination of the gases of the atmosphere forming nitric oxide. A few years later Lord Rayleigh made use of this method in his work on Argon, that remarkable discovery which so wonderfully confirmed the early observation of Cavendish. Lord Rayleigh made many attempts to improve the efficiency of his apparatus and even on a small scale achieved a considerable measure of success. He found that a kilowatt hour would produce fifty grammes of nitric acid. With continuous working this works out to 360 kilos. per kilowatt year. The most efficient modern plant gives about 600 kilos. per kilowatt year.

In 1902 a company was started to make use of some of the power from the Niagara Power Station for the production of nitrate, but the method employed was not efficient, the plant was very costly, and the scheme failed. The credit of producing the first really practical plant belongs to Prof. Birkeland and Eyde. They erected the first large works at Notodden, where the power of three waterfalls was brought into play, the h.p. developed being about 70,000. The apparatus invented by Birkeland for the electrical treatment of the air consisted of a disc-shaped furnace lined with firebrick in which the electric arc was produced. Birkeland had observed that when an arc produced from an alternating current was acted upon by a powerful magnet it was thrown into a flat disc. Such an arc is produced in the disc-shaped chamber of the furnace and a powerful current of air is driven through it, entering the furnace through the centre and being drawn off at the circumference. The current employed in the Notodden works is alternating at 5,000 volts, and each of the older furnaces took some 800 K.V.A., the disc of flame in these latter being about three metres in diameter. (Furnaces have more recently been constructed which absorb 4,000 K.V.A.) By rapid cooling of the outgoing air the oxide of nitrogen is saved from decomposition and the gases are then treated in suitable washing towers with the production of nitric acid, and nitrates of lime and soda.

Numerous experiments have shown that the degree of combination taking place is dependent entirely on the temperature, that is, of course,

when working with a mixture containing the same proportions of nitrogen and oxygen, and that even at a temperature of  $3000^{\circ}\text{C}$ . only some five per cent of the gases combine. Another fact which renders the process difficult is that the gas must not be kept at this temperature for any length of time, as at such high temperature the nitric oxide is rapidly dissociated; as a result the conditions to be aimed at are a very rapid heating to a high temperature and a very rapid cooling. In the Birkeland furnace the heating is indeed rapid, but the cooling is by no means so easy to accomplish.

From what has been said it will, I think, be evident that for the manufacture of electric nitrates, etc., to be successful the supply of power must be large and cheap. I have seen it stated that it is only possible to work profitably if the power costs less than one twenty-fourth of a penny per unit. At the present time quite a large amount of power is being made use of in Norway for the production of nitrates. It is estimated that altogether there are some six million h.p. available in that country.

Other forms of furnace have been devised of which that of Schönherr is the most widely used; this is the pattern which has been very largely used by the Bädische Anilin Soda Fabrik and has probably played a very important part in the production of explosives for Germany. In this form of apparatus an arc is produced in a long tube and the air is made to travel through the tube and around the arc in a spiral. The arc terminates in a water-cooled chamber in which the gases are rapidly cooled to about  $600^{\circ}\text{C}$ . The arc starts from a massive iron electrode and is so intense that the end is at once melted and the ferric oxide formed is literally boiled away. Comparative trials of this form with Birkeland's show that the Schönherr furnace has the greater efficiency.

Per K.V.A. hour.

Birkeland and Eyde	70 grammes $\text{HNO}_3$	2 per cent NO
Schönherr ... ..	75       ,,       ,,	2.5       ,,

per kilowatt-hour. Several other types of furnace have been devised but are not employed on any large scale.

It may at first seem strange that so great an amount of power is needed to produce such a comparatively small result. The reason for this is that the chemical combination of nitrogen with oxygen is accompanied by an absorption and not an evolution of heat, as is the case with most of the common chemical reactions with which we are familiar. As a result of this the reaction will at once cease if the supply of energy is cut off. It appears that the action of the arc is purely a thermal one; that any other method of heating would be equally successful, but the electrical method is the more convenient. On account of the fact that the combination will not take place without a

large supply of heat energy the flame does not spread and the reaction takes place only in the hottest part of the electric flame.

Although these methods have only an efficiency of some sixty to seventy per cent, yet where an abundant supply of cheap power is available they seem likely to hold their own, at least for a time.

It must not be supposed that this is by any means the only method of fixing the nitrogen of the air ; there are several others, some of which seem likely to take an important place in the production of fertilizers and similar nitrogenous compounds. One of the earliest and also the most successful was the formation of what is called cyanamide, a compound of calcium with carbon and nitrogen which easily gives off ammonia. You are all familiar with the carbide which we use for the production of acetylene ; it also is a product of the electric furnace and is produced by heating very strongly a mixture of lime and coal. Now it was found by Frank and Caro that if this carbide were heated in an atmosphere of nitrogen the latter was absorbed, with the formation of calcium cyanamide, a substance which though stable under ordinary conditions is decomposed in the presence of water, with the formation of ammonia. This material has now been on the market for some years and has been extensively used as a fertilizer. It is generally regarded as inferior to nitrate because it may exert a harmful action on the crop if it is used without sufficient care.

Two methods are employed for obtaining a supply of pure nitrogen for the manufacture of cyanamide. In the first, which is purely chemical, air is passed over heated copper which removes the oxygen, leaving nitrogen, which is collected in holders and then pumped into the furnace containing the heated carbide. The oxide of copper is reduced by means of a current of "producer" or "water" gas, when it will again be ready to absorb oxygen. This method is, I believe, already obsolete. It has given way to a physical method by which the two gases, oxygen and nitrogen, are separated by a process of fractional distillation. This process, which is really very similar to that employed in the production of strong spirit from a weak solution of alcohol, such as is produced by fermentation, is in reality merely a process of rectification.

The air is first liquefied by great pressure and cold and then rectified in an apparatus very similar in principle to that employed in the manufacture of alcohol.

Nitrogen boils at	196° C.	77° absolute
Oxygen boils at	183° „	90° „

The final result of the process is that pure nitrogen comes away as gas and liquid oxygen may be continually drawn off from the

apparatus. A very large plant of this kind working at Odda, in Norway, is capable of turning out 13,000 cubic feet of nitrogen per hour with an expenditure of some 200 h.p.

A current of liquid air is allowed to run down the rectifying column, which is built up of trays, perforated and filled with glass beads. In passing down this column the liquid air meets with an ascending current of gases which are evaporating from the mixture of liquid oxygen in the still; an interchange of heat takes place, some of the oxygen in the gases travelling up the column is condensed to liquid while the heat given up by the liquid causes the evaporation of an equivalent amount of nitrogen. This happens throughout the whole of the passage of the liquid and gases down and up the column, with the result that almost pure nitrogen issues from the top of the column while the liquid in the still becomes so rich in oxygen that it can be drawn off and used for the production of this gas. The nitrogen which is pumped off from the rectifier is passed into holders and so into the retorts containing the heated carbide.



The mixture of calcium cyanamide and carbon which is thus produced is allowed to cool out of contact with air and then ground.

It has been found that if seeds are sown in land to which cyanamide has been applied just previously the germination and also the subsequent growth is adversely affected, so that it is desirable to apply cyanamide some little while before sowing the crop. Even then it is rare that cyanamide will give so good results as equivalent amounts of nitrogen applied in the form of either nitrate of soda or lime, or sulphate of ammonia. (See Appendix recording experiments on maize.)

By treating cyanamide with superheated steam ammonia is produced thus :—



This ammonia can then be converted into nitric acid by the catalytic process invented by Ostwald. In this the ammonia is passed with air or oxygen through porous plugs in which is a quantity of very finely divided platinum; when the correct conditions are maintained the ammonia is oxidized with the formation of nitric acid.

Of the remaining processes for bringing about the combination of nitrogen the method of causing the nitrogen to combine with hydrogen, invented by Haber, is by far the most important. This process was without doubt a very great asset to Germany during the war when it was cut off from outside supplies of nitrates. Unfortunately very few details as to the working of this process have been published.



It had but reached the experimental stage at the commencement of the war. It was at once seen that it was a question of vital importance to Germany to be in a position to make a sufficiency of nitrates for the manufacture of explosives. Much artificial nitrate may have been imported from Norway and Sweden, but Chile, the main source of supply, was soon cut off.

In the Haber process for the synthesis of ammonia, nitrogen and hydrogen in the proportions of one to three by volume are compressed to 150–200 atmospheres pressure and passed over certain catalytic substances at a temperature of about 500° C. At this temperature and in the presence of these special substances whose exact nature, has, I believe, not been made public,\*—though it is known that a large number of substances are effective—a certain amount of the nitrogen and hydrogen combine to form ammonia. The gases now pass to a chamber kept at a very low temperature (about 40° C.), where the ammonia liquefies and can be drawn off as liquid or allowed to expand as gas and is then converted into sulphate of ammonia. It can also be converted into nitric acid by the Ostwald process. It was by this means that Germany obtained the large supplies of nitrate for the manufacture of explosives. It has been estimated that the B.A.S.F., who employ this Haber process, produced some 500,000 tons of ammonia per annum; this, when oxidized, would yield some two million tons of nitric acid at least.

Such, then, are the more important methods by which the free nitrogen of the atmosphere can be brought into combination by purely chemical means. There remain, however, the biological methods, which so far as agriculture is concerned, are of vast importance. In this case the fixation of nitrogen is brought about by bacteria found in soil. The soil bacteria which are capable of bringing about this nitrogen fixation are of two classes: the one is symbiotic, that is to say, it cannot carry on without the assistance of some other organism. In this particular case the organism necessary as host is a plant of the leguminous family: beans, *berseem*, peas, clovers, vetches, etc. It had long been observed that plants of this natural order seemed to be almost independent of manures and also that where beans and wheat happened to be growing side by side, as often happens when wheat is sown after beans and many of the latter have shelled and been left on the field, that the wheat was very much stronger in the immediate neighbourhood of the beans. The cause of this was shown by Hellriegel and Wilfarth and afterwards confirmed in a most complete manner by a long series of experiments carried out by Sir John Lawes and Sir Henry Gilbert at Rothamsted. These bacteria play a most important part in

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\* In 1919. F.H.

agriculture and are one of the main reasons why “rotations” of crops are so advantageous. The other class of bacteria which are capable of causing combination of nitrogen are those known as *Azotobacter*; these are present in most soils and are found to be very abundant in many of the more fertile soils of this country. Although they add to the soil’s store of nitrogen they do not appear to play so important a part as the other class which supplies the *leguminosæ* with their nitrogen.

Now let us see how this question affects this country and what are the possible developments. Before the war Egypt expended some L.E. 600,000 annually on fertilizers, the most part of this was for nitrate of soda and sulphate of ammonia. One cannot possibly be exaggerating in saying that this could easily be increased to an annual purchase of at least one million pounds worth of fertilizers. Among the various nitrogenous fertilizers now being produced in large quantity, the question naturally arises: which is a suitable manure for Egypt, and if so, can we produce it in the country?

So far as the former part of this question is concerned, I much regret that practically no really reliable experiments have been, so far as I am aware, made with nitrate of lime on Egyptian soils. A few pot experiments have been made by myself with maize\* and the results showed conclusively that the nitrate of lime could very well replace nitrate of soda and was indeed slightly superior. If we argue on *a priori* grounds I think we may safely conclude that nitrate of lime should prove a very suitable fertilizer for this country. As many, and probably all of you are aware, one of the gravest troubles against which cultivators in this country have to contend is the presence of small quantities of various sodium salts in the soil. The salts usually met with are the chloride, sulphate and bicarbonate. More rarely we have carbonate, which is the most troublesome of all. Now the plant does not require sodium as one of the essential elements for its growth, and it is quite possible that when sodium nitrate is applied to the soil that it is not absorbed by the plant in this very form but undergoes a chemical change; the nitrogen may be taken up in the form of nitrate of potash or possibly as nitrate of lime. Now when nitrate of soda is employed the soda will be left behind and will add to the amount of soda salts already present. It is a small amount perhaps, but if this process is continued we shall, unless drainage is good, run a risk of adding to instead of reducing the salinity of the soil. On the other hand, even if the lime of the nitrate is not taken up by the plant to its full extent, what is left would be in the form of carbonate, which is not only harmless but in many cases actually beneficial to the soil and crops. There are two drawbacks to the use

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\* See Appendix.

of nitrate of lime. It is slightly deliquescent and for this reason must be transported in barrels or drums and not sacks; in this country it is possible this property might not prove so great a difficulty as has been found in damper climates. The other is that the material being very slightly alkaline, and for that reason caustic, it has an injurious action on clothes and, if care is not taken, on the skin.\* This difficulty would not be a serious one, since the *fellah* wears cotton clothes and a canal is usually handy where he can get a wash after he has been occupied in broad-casting the nitrate.

Now what are the possibilities of producing electric nitrate in this country? We have at Aswân a source of power which, if suitably controlled, would give an average of well over 250,000 horsepower for about one half the year. This, according to the figures which I quoted above should, even at the present efficiency of working, give some 75,000 tons of nitrate of lime for the six months, or more than the pre-war demand of the country. Whether it would be advisable for the factory to be built at Aswân or whether it would be better to convey the power to some point where limestone was more accessible is a matter which would have to be thoroughly discussed. One of the greatest difficulties to be overcome would be the production of the necessary amount of quicklime, the fuel for this part of the process being a very expensive item. The electric power might possibly be employed, but this would be an extravagance.

It is interesting to compare the various nitrogenous fertilizers as to their respective richness in the important element. This is a point which is too often neglected and which is of special importance in a country like this, where frequently the cost of transport is a very considerable item in the cost of such materials. Assuming that the freight per ton is the same for all the different fertilizers, it is very evident that the distance to which a poor manure can be profitably carried is very much less than the distance to which we might transport a rich manure at a profit.

TABLE SHOWING NITROGEN CONTENT OF FERTILIZERS.

	Per Cent Nitrogen.
Nitrate of soda... ..	15
Sulphate of ammonia ... ..	21
Nitrate of lime... ..	13
Cyanamide (variable) ... ..	17-21
Nitrate of ammonia ... ..	35
Urea 95 per cent ... ..	45

In estimating the values of fertilizers it is customary to speak of the cost per unit. Let me explain briefly what is meant by this.

\* This objection has now been overcome. The material now made is in excellent condition for distribution. Waterproofed sacks are now sometimes employed.—F.H. 1921.

If you look at the table you will see the proportion of nitrogen which is present in the various substances with which we have been dealing. Now, under ordinary conditions a ton of nitrate of soda was worth L.E. 10; it contains fifteen per cent of nitrogen. Divide L.E. 10 by 15 and we get the cost of one per cent of nitrogen in a ton of material. This is what is called the price per unit. Now, if the nitrogen in all these various fertilizers may be assumed to be of equal value, it is easy to compare the price of nitrate and so determine the value of the manure in question. So far so good, but these prices are for the material put on rail: we want to know the price at the farm. Various waste and refuse materials are now being put on the market in this country, but being all of a very poor quality it does not pay to carry them to any great distance, and for this reason they must have a rather limited application; and for the land which is difficult of access it is evident that the most concentrated fertilizer will be the one to buy. The matter is not really quite so simple as this, because the price per unit increases with the concentration, so, that the benefit which should accrue from the use of a concentrated material is somewhat discounted by the relatively higher price.

It is stated that urea is being produced synthetically in Germany from ammonia, ammonium carbonate being the intermediate product; if this can be done in an economical manner it is evident that a most concentrated fertilizer will result. The nitrogen which is present in urea is of the same value from a fertilizing point of view as the nitrogen in ammonia, which is again of practically the same value as that in nitrate of soda. The interesting feature as regards urea is that it does not contain any metallic base or any acid. When it decomposes, it does so into ammonia and carbon dioxide.

This principle of preparing concentrated fertilizers where transport is expensive has long been applied to phosphatic manures. The ordinary "Super" of commerce, such as is employed in this country, contains some 17 to 18 per cent of phosphoric acid, but a "concentrated" or double super can be purchased which contains 38 to 43.8 per cent. Obviously, if there is not too great a difference in the cost per unit the latter will be the more profitable to employ in those places where transport forms a great part of the expense.

And now, supposing we have this supply of nitrogenous fertilizers, which for the sake of argument we may put at 100,000 tons per annum, let us say 50,000 produced locally and an equal amount imported. This quantity will be sufficient for one million feddâns of cereals and should give an increase in the crops of at least a million and a quarter *ardeb*s of grain, or say *six million bushels*. The total crop of the country, so far as wheat goes, is about thirty-five million bushels, so that the increase would be quite noticeable, amounting to about seventeen per cent.

## APPENDIX.

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### POT EXPERIMENT WITH VARIOUS NITROGENOUS MANURES.

The very extensive and growing use of artificial nitrogenous fertilizers in Egypt renders the introduction of the new manures, prepared from atmospheric nitrogen, a matter of no little interest. The production of these fertilizers bids fair to increase very rapidly, especially should the new processes of Ostwald prove successful on the large commercial scale. The interest is made even greater by the possibility of these substances being produced in this country should the Aswân Power Scheme become an accomplished fact.

While there is no doubt that the final test of any fertilizer must always be made on the large scale in the field, still there is always a great deal of information to be obtained from experiments in pots, if these are carried out with sufficient care. In this country, in summer, one's choice of crops which are at all suitable for cultivation under these conditions is extremely limited, and indeed maize appears to be the only plant available. Owing to its very rapid growth it is evident that only those fertilizers which are of almost immediate availability will prove of value. This fact must be borne in mind when considering the results of the experiment now to be described.

In comparing fertilizers which provide the same ingredient two courses are open. Either equal money values of the various manures may be applied and the increases in yield over a control plot compared, or equal weights of the particular constituent (*e.g.* nitrogen) may be employed and the relative efficiency calculated from the results by comparing the increases brought about by the different manures with that obtained by some standard material, in this case nitrate of soda. In the present instance the latter course was adopted.

The pots used for this experiment each contained twenty-two kilos. of soil, taken from the Nile bank. This had been thoroughly mixed and was consequently uniform in character. The following table shows the quantity of the various manures employed. These quantities are so calculated as to supply the same amount of nitrogen as that contained in ten grammes of nitrate of soda (ninety-six per cent). All the manures were applied in two equal dressings. The first half of the cyanamide in Nos. 7 and 8 was applied before sowing, that in Nos. 11 and 12 after sowing, at the same time as the remaining manures. Six grammes of sodium phosphate and four grammes of potassium chloride were also applied to each pot. This also

was put on in two instalments. There was no drainage to the pots. The plants were watered with filtered Nile water. Four plants were allowed to remain in each pot.

		Quantity (Total).	Average Weight of Plant.	Gain over Unmanured (mean).
		Grammes.	Grammes.	Grammes.
1 and 2	No nitrogenous manure ... ..	—	42	—
3	4 Nitrate of soda... ..	10	145	103
5	6 Sulphate of ammonia ... ..	7·8	139	97
7	8 Cyanamide... ..	11	112	70
9	10 No nitrogenous manure ... ..	—	42	—
11	12 Cyanamide ... ..	11	99	55
13	14 Nitrate of lime (Notodden)	11	153	111
15	16 Nitrate of soda ... ..	10	159	117
17	18 Nitrate of soda ... ..	10	139	97
19	20 Castor meal ... ..	30·6	96	54
21	22 Sewage sludge ... ..	100·0	66	24
24	34 Ammonium nitrate ... ..	4·7	146	104

The two organic manures have obviously done but little good, probably owing to the very short duration of the experiment and partly owing to the fact that with so restricted a root system the soil had to be kept very wet or flagging took place. It is unfair therefore to compare these with the "artificials."

Taking the increase brought about by nitrate of soda (average) as 100, we get the following :—

Nitrate of soda ... ..	100
Sulphate of ammonia ... ..	92
Cyanamide (average) ... ..	59
Nitrate of lime ... ..	104
Nitrate of ammonia ... ..	98

Cyanamide therefore is not so efficient as the nitrates under the conditions of this experiment, while ammoniacal nitrogen appears to have an equal value. The slowness of action of the organic manures appears to be due to a failure to convert the organic nitrogen into ammonia rather than a failure to change the latter to nitrate. This is shown by the fact that ammonium sulphate gives a good result. The time factor is no doubt, as mentioned above, of importance in this connection.

The results obtained accord very well with those made both in pots and the field in Germany. Nitrate of lime has almost invariably proved more efficient than nitrate of soda. In this experiment the plants receiving nitrate of lime appeared especially robust. The action of nitrate of ammonia is interesting;

it is a most concentrated manure and leaves no residue.\* Its constituents are entirely gaseous. Probably its hygroscopic nature will prevent its use as a manure except under special circumstances, as for example, where heavy transport demands the most concentrated fertilizer. It contains weight for weight more than double the amount of nitrogen that is present in nitrate of soda.

Sulphate of ammonia has proved almost the equivalent of nitrate of soda. This is surprising, considering the short time the plants were growing, but is probably due to the high temperature of the soil. Cyanamide has shown only about seventy per cent of the efficiency of nitrate of soda. Whether the remaining nitrogen has been lost or is merely unavailable can only be shown by further experiment. It is hoped to make a number of similar experiments on winter crops in order to determine the relative values of the manures at all seasons.

The appearance of the crop at the termination of the experiment is shown in the accompanying photographs (Plates I, II, and III).

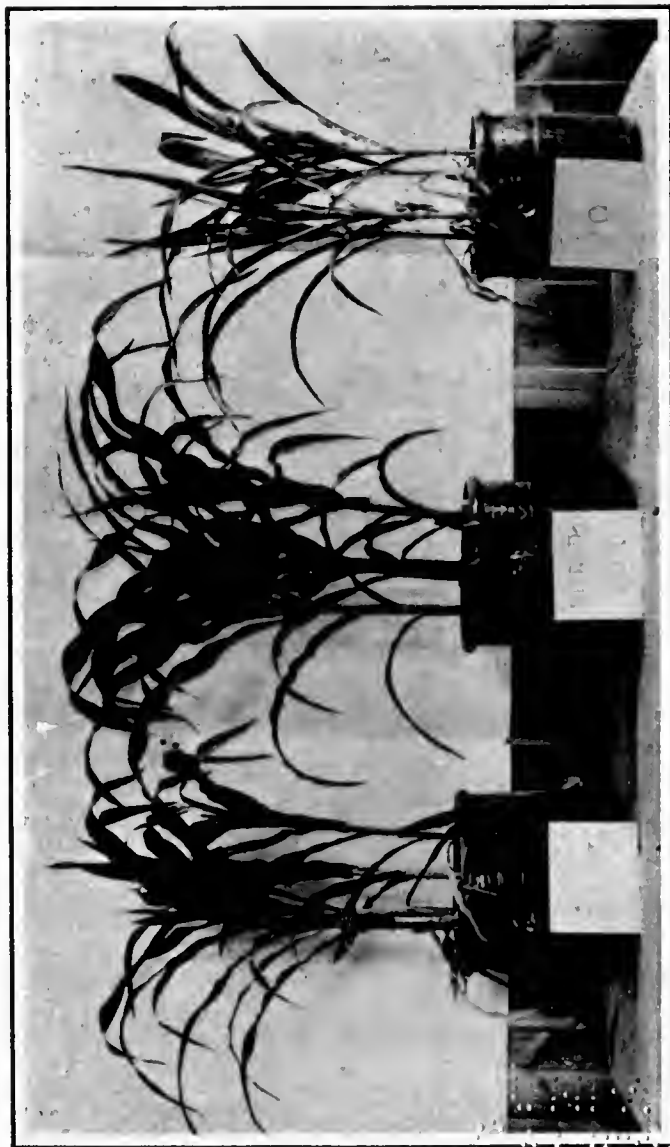
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\* Since the above was written synthetic urea has also been suggested as a concentrated nitrogenous manure. If this substance were produced on a commercial scale of a purity of 95 per cent it would contain 47 per cent of nitrogen or more than three times as much as nitrate of soda and twice as much as sulphate of ammonia.—F.H.





PLATE I.



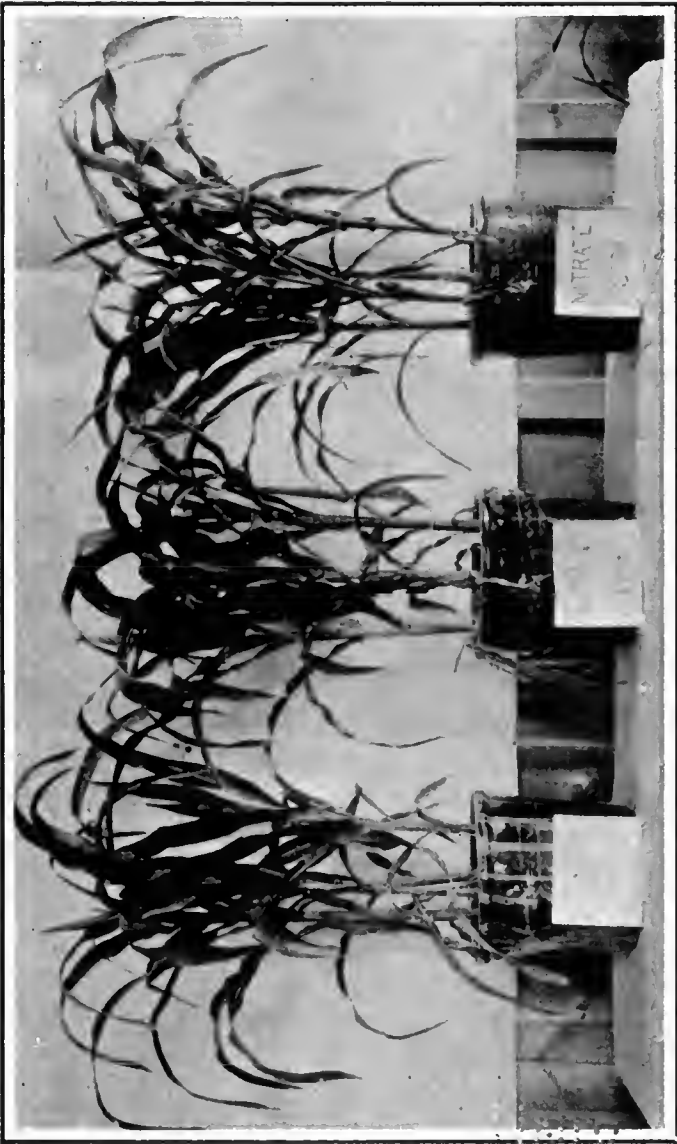
Cyanamide.

Nitrate  
of  
Soda.

No  
Nitrogenous  
Manure.



PLATE II.



Nitrate  
of  
Ammonia.

Nitrate  
of  
Lime.

Nitrate  
of  
Soda.

70 1980  
1980-1980

PLATE III.



Nitrate  
of  
Lime.

Nitrate  
of  
Soda.

No  
Nitrogenous  
Manure.

100-1000



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